NH_3, H_2S, and the Radio Brightness Temperature Spectra of the Giant Planets

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Recent radio interferometer observations of Neptune enable comparisons of the radio brightness temperature (T_B) spectra of all four giant planets. Figures 1, 2, 3, and 4 show the T_B spectra of Jupiter, Saturn, Uranus, and Neptune, respectively, from 0.1 10 tens of cm wavelength. The data shown are collected from many observers. Data for Jupiter, Saturn, and Uranus arc those cataloged by de Pater and Massie [1985], plus the Saturn VLA data by Grossman *et al.* [1989]. Figure 3, Uranus, shows only data acquired since 1973. Before 1973 Uranus' T_B increased steadily as its pole moved into view, causing significant scatter in those data. Neptune data at >1 cm, all taken at the VLA, arc collected from de Pater and Richmond [1989], dc Pater *et al.* [1991], and Hofstadter [1993]. For a variety of reasons, siaglc-dish data at those wavelengths arc much noisier than the more reliable VLA data and have been ignored. Single-dish data by Griffin and Orton [1993] shortward of 0.4 cm arc shown, along with the OVRO datum at 0.266 cm by Muhleman and Berge [1991].

Spectra of Jupiter, Saturn, and Neptune share certain gross characteristics. In each case T_B at 0.1 cm is within -30 K of that at 1.3 cm, which is in the 120-140 K range. The spectra increase monotonicall y with wavelength only longward of 1.3 cm. Ammonia (NH_3), whose strong inversion spectrum peaks at -1.3 cm, is known to be an important tropospheric const ituent at Jupiter and Saturn. Its signature on the Jovian spectrum is obvious, causing the prominent "hole" at 1.3 cm. At Saturn it is a bit more subdued but is the source of that spectrum's change in slope at 1,3 cm. Radiative transfer models of Jupiter and Saturn using near-solar deep NH_3 abundances agree well with the data [de Pater, 1990].

Uranus' T_B spectrum dots not fit this pattern. It increases monotonicall y with wavelength over the entire range shown in figure 3, with no evidence of a break in slope near 1.3 cm. T_B is -175 K at 1.3 cm, -80 K warmer than at 0.1 cm and much warmer than the other three planets. At -20 cm and 0.1-0.4 cm Uranus' T_B arc quite close to Neptune's, but in the 1-10 cm range Uranus averages 30-50 K colder than Neptune. Gulkis *et al.* [1978] first showed that Uranus radiative transfer models with near-solar NH_3 deep abundances predict T_B at cm wavelengths that arc much too cold. Using an NH_3 abundance about 1% of solar fit the data best, but far from pert'cctly. They offered one possible cause for the apparent NH_3 depletion: a superabundance of H_2S could react out most of the NH_3. Note the H_2S was postulated. "There is no direct observational evidence of H_2S, which has not yet been detected at any of the giant planets. It was merely considered the most likely candidate to deplete NH_3.

Some researchers suggest a significant H_2S superabundance at Neptune also. Problems fitting radiative transfer models to cm data prompted de Pater *et al.* [1991] to invoke NH_3-depleting H_2S at Neptune, and to suggest that H_2S

might contribute significantly 10 the total opacity. Recently DeBoer and Steffes [1994] (hereafter DBS) made lab measurements of cm H_2S opacities and found them a factor of two larger than Van Vleck-Weisskopf predictions. Based on this they suggest H_2S may be the major source of cm opacity in Neptune's upper troposphere, and reinterpret Lindal's [1992] Voyager 2 radio occultation data. Lindal assumed all opacity at the 6.3 bar level, the deepest probed, was due 10 NH_3 and derived a number mixing ratio of 5×10^{-7}. DBS assume all opacity there is due to H_2S aod derive a mixing ratio of 1.7×10^{-4}. For support they compare radiative transfer model results m the T_B data, but rely heavily on the very noisy single-dish data at > 1 tin, where the VLA data arc much more reliable.

Figure 5 duplicates Figure 4 except it includes results from various radiative transfer models. Models 1-4 arc after DBS, with 30 times solar H_2O and CH_4; NH_3 and H_2S abundances, respectively, are 0.5 solar and 15 times solar for model 1, solar and 18 times solar for model 2, twice solar and 25 times solar for model 3, and solar and 6 times solar for model 4. Models 1-3, which arc identical shortward of 6 cm, yield 1.7×10^{-4} H_2S above the NH_4SH cloud, while model 4 yields Lindal's 5×10^{-7} NH_3. Model 5 is after de Pater and Richmond [1989], using an ~2% solar NH_3 mixing ratio (3×10^{-6}) throughout the atmosphere, limited by saturation. Model 6, by the author, uscs approximately solar NH_3 (2×10^{-4}) and no H_2S to demonstrate that Neptune models with uniformly near-solar NH_3 abundances arc inconsistent with the observed spectrum.

Only the models with NH_3 above the NH_4SH cloud reproduce Neptune's T_B dip at cm wavelengths. Model 5, with more NH_3 than model 4, provides the best fit; even more NH_3 would provide a better fit, further decreasing T_B shortward of 1 tin. This dots not conflict with Lindal's result, since he states NH_3 is probably still saturated at the deepest datum. Due to the H_2S spectrum's simple f^2 dependency longward of 0.4 cm, models dominated by H_2S above the NH_4SH cloud (DBS models 1-3) deviate <10 K from a straight line on the plot, quite unlike the data. Reproducing the T_B dip with such an absorber requires a relatively this tropospheric layer with a much larger absorber mixing ratio than adjacent layers. Since there is no viable mechanism to maintain such a layer, it is highly unlikely that the observed cm opacity in Neptune's upper troposphere is primarily due (o H_2S. Thus Neptune's radio spectrum requires NH_3, or another species with an opacity peak near 1-2 cm, in the upper troposphere.

Applying the DBS models 1-3 to Uranus leads to a different conclusion for that planet. Upper tropospheric T-P (temperature-pressure) relations for Uranus and Neptune arc very similar; al equal pressures, their temperatures differ by ~5K at most from well above their tropospheres to the deepest level probed by radio occultation [Lindal *et al.*, 1987; Lindal, 1992]. Given a fixed set of constituent abundance profiles, a model using Neptune's T-P profile will yield a T_B spectrum quite similar to one produced using Uranus' T-P profile. The dissimilarity of the two planets' observed radio spectra makes it unlikely they have similar constituent profiles. Figure 6 shows the result of using DBS' H_2S-dominated models of Neptune as first approximations to such models for Uranus. The models fit Uranus' observed spectrum much better than Neptune's, suggesting that tropospheric constituents whose cm opacities have f^2 dependencies, such as H_2S, are sufficient to explain Uranus' radio T_B spectrum. Thus, while Neptune seems to need a small (relative to solar) but nontrivial amount of NH_3 in its upper troposphere, Uranus does not.

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Figure 1: Jupiter Brightness Temperature Spectrum

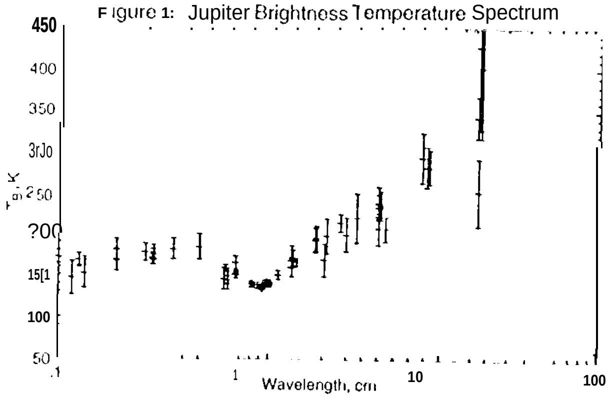


Figure 2: Saturn Brightness Temperature Spectrum

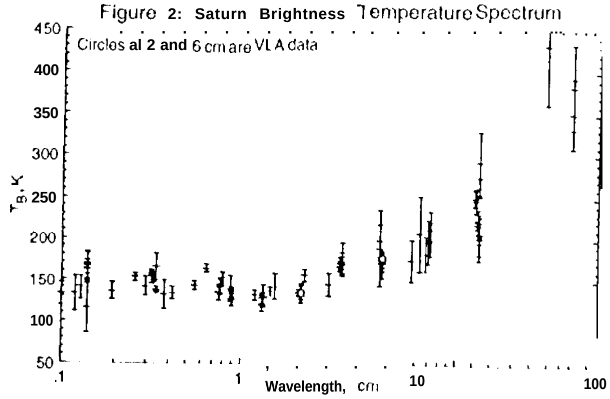


Figure 3: Uranus Brightness Temperature Spectrum

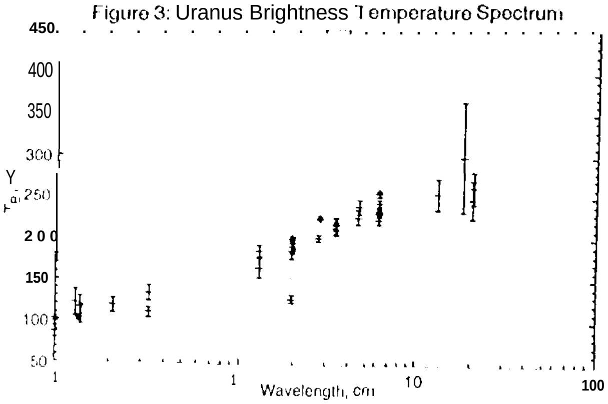


Figure 4: Neptune Brightness Temperature Spectrum

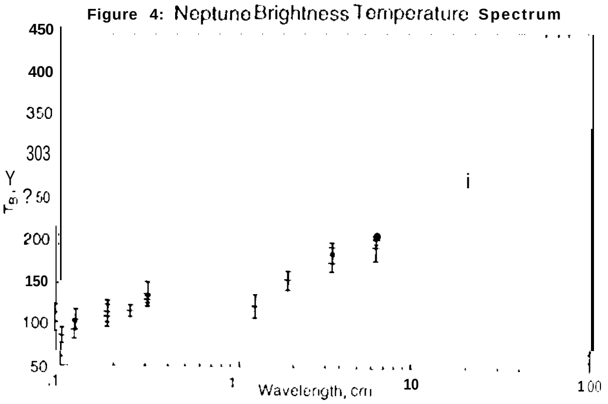


Figure 5: Modeling Neptune's Brightness Temperature Spectrum

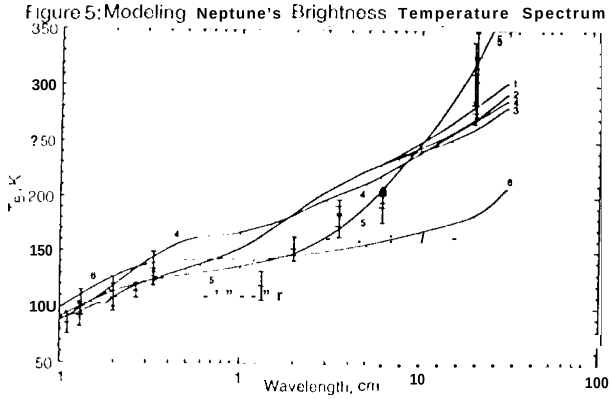
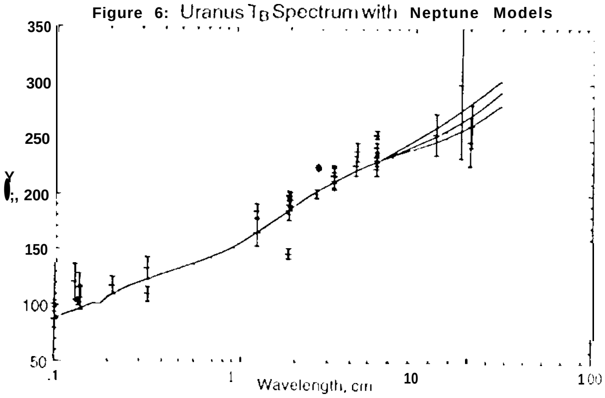


Figure 6: Uranus T_B Spectrum with Neptune Models



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